Exhibition of an Improved Apparatus for the Therapeutic Use of Compressed and Rarefied Air; with Remarks on the Home-Treatment of Pulmonary Affections.

BY

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not before this body. But the apparatus for expiration into rarefied air has not yet been publicly described.

My attention had been called to the value of modifications of respiratory pressures in the treatment of pulmonary affections, and especially of phthisis, even before I became a student of medicine, by some rather remarkable recoveries ensuing upon such treatment in the practice of my brother. The apparatus which he employed was that of Waldenburg. A description of this instrument, by Dr. Pepper, and remarks upon its therapeutic employment by Dr. J. Solis-Cohen, may be found in the proceedings of the college (Feb. 2, 1876), "Transactions," third series, vol. ii.

Much of the success of this therapeutic measure depends upon its regular and continuous use. To insure this at such times as visits to the physician's office are impracticable, the apparatus must be placed in the patient's home. Waldenburg's apparatus is large and cumbersome. It is not continuous in action, its adjustment is troublesome, and its cost, fifteen years ago, was excessive. These considerations induced my brother to undertake some experiments with the view of providing a substitute which should be small, cheap, easily managed by a patient or nurse, and reliable as well as cleanly. He, however, abandoned the gasometer plan, and his efforts were not entirely successful. Taking the matter up where he had left off, I soon realized that the only available method of securing a certain, regular, and continuous pressure was to return to the gasometer; but I found that the desired reduction in size could be accomplished by using the gasometer as a regulator only, and not as a reservoir. This necessitated the introduction of another source of air supply; and as the simplest, cheapest, and most practicable, I chose the foot-bellows of the dentist's blow-pipe. Any form of pump available under the particular conditions, or even city water pressure, might also be adapted; but the bellows is preferable under ordinary circumstances. This combination of foot-bellows and small gasometer solved the problem so far as the inhalation of compressed air is concerned. With the assistance of Mr. Charles Richardson an apparatus was constructed in 1883 which has been in continuous use ever since by others as well as by myself, and has given complete satisfaction. Though it has already been described in print,* I may be pardoned for again exhibiting its construction, as several mechanical improvements have been introduced that have not yet been published.

It consists of a gasometer ("Compressed air," Fig. 1), of which the air chamber is eight inches in diameter and twenty-four inches high. The water chamber is pierced at the level of the base of the overflow tank (seven inches from the top) with a row of perforations, allowing the water to escape into the tank under pressure of air in the air cylinder. The air cylinder carries, two inches † from its open base, two shelves, one on each side, on which are placed ballast-weights for the purpose of lowering the center of gravity, and thus maintaining the steadiness of the apparatus. Both shelves and weights are perforated to avoid resistance of water. As the area of the top of the air chamber is just fifty square inches, atmospheric pressure upon it equals, in round numbers, 750 pounds. With the ballast upon its shelves, the cylinder weighs ten pounds, giving an excess pressure of $\frac{1}{75}$ atmosphere. Weights are furnished in two sizes, in the shape of rectangular blocks of iron $4\frac{1}{2}$ by 2 inches surface, and about $\frac{1}{2}$ inch and 1 inch thick, respectively. The smaller ones are bored out to weigh $1\frac{1}{4}$ pound each; the larger ones to weigh $2\frac{1}{2}$ pounds each.

* "N. Y. Med. Jour.," Oct. 18, 1884, and other places.

† The shelves have been raised to avoid catching the weight of the escape-valve.

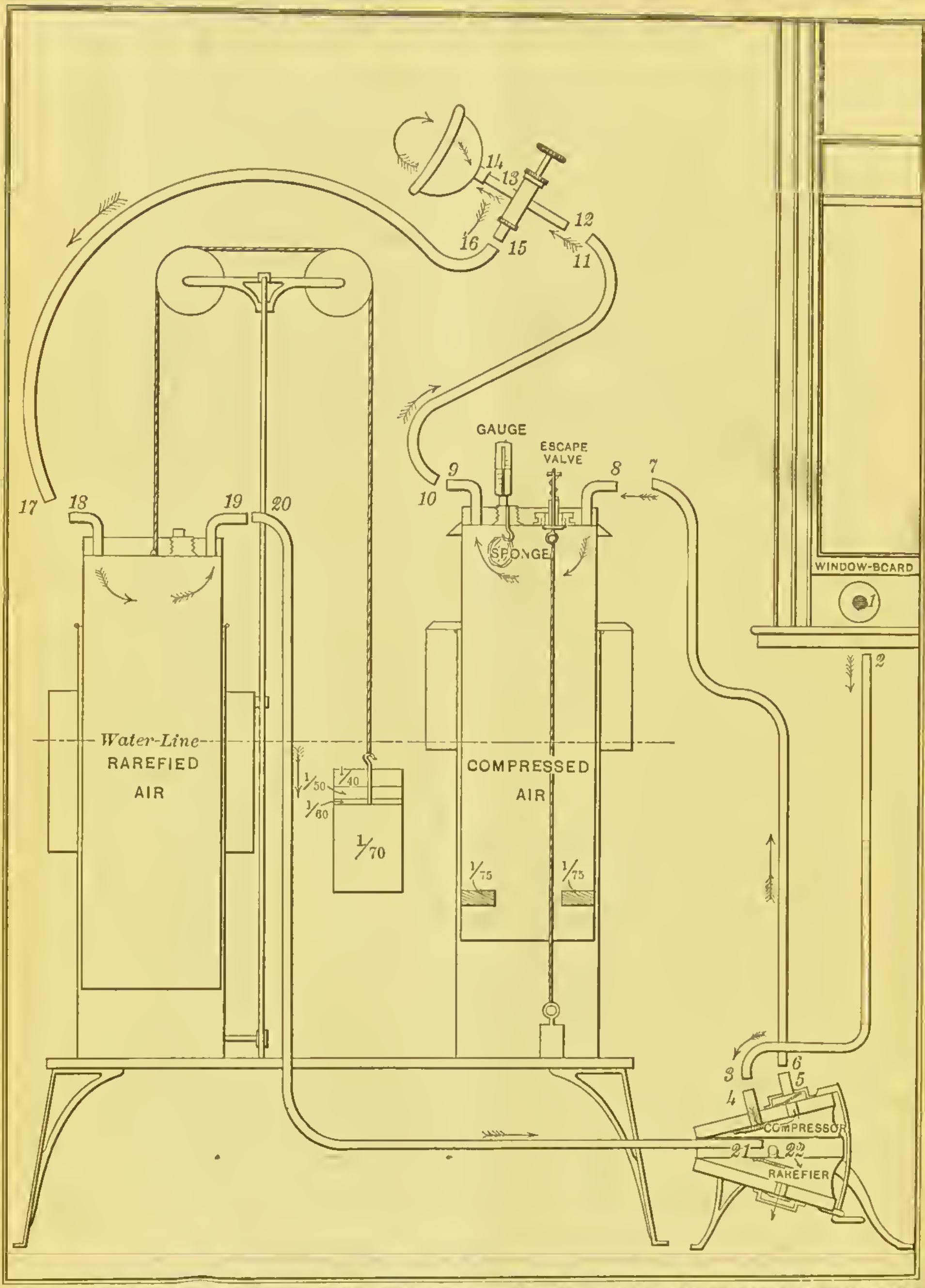

Fig. 1.—Explanation of figure. The parts are numbered in order of attachment, and in the direction of air-current; from the window to the mask through the compressed-air gasometer; and from the mask to the discharge pipe of the rarefying bellows through the rarefied-air gasometer. The discharge-pipe may also be connected with window if desired. The direction of air-current is indicated by the arrows.

Being placed on top of the air chamber in successive pairs (one on each side, to preserve balance), they bring the pressure up to any desired amount not exceeding + $\frac{1}{30}$ atmosphere. Thus:

Cylinder and bottom weights = 10 lbs. = + $\frac{1}{75}$ atmosphere.
$2\frac{1}{2}$ lbs. (two small weights) additional = $12\frac{1}{2}$ lbs. = + $\frac{1}{60}$ atmosphere.
$2\frac{1}{2}$ lbs. (two small weights) additional = 15 lbs. = + $\frac{1}{50}$ atmosphere.
$3\frac{3}{4}$ lbs. (one small weight and one large weight) additional = $18\frac{3}{4}$ lbs. = + $\frac{1}{40}$ atmosphere.
$6\frac{1}{4}$ lbs. (one small weight and two large weights) additional = 25 lbs. = + $\frac{1}{30}$ atmosphere.

The air cylinder is furnished with two goose-necks, one (8) for the attachment of the tube (6, 7) from the bellows, conveying compressed air; the other (9) for attachment of the tube (10, 11) connected with the stop-cock (12, 13) and face-mask (14) or mouth-piece, through which the patient inhales. A perforation two inches in diameter is fitted with a screw cap carrying a hook on which a sponge may be placed, which is to be saturated with any volatile medicament (*e. g.*, terebene) that may be desired. The cap likewise contains a smaller perforation, into which an air-gauge may be fitted. When the gauge is not in use this is closed with a rubber plug. Still another perforation in the top of the air chamber is fitted with a valve, which permits escape of air should too much be sent over from the bellows. This valve, which is superior to my own arrangement for the same purpose, is the ingenious device of Mr. F. Metzger, of this city, who now makes the apparatus in every respect according to my instructions, and who has devoted much time and care to the details of construction in order to secure both strength and lightness. The escape valve is composed of two flat plates of brass, the upper perforated, the lower unperforated. They are held in apposition by a spring, and when in apposition no air escapes. The lower plate carries a chain, thirty-five inches long, which is attached to a weight which rests upon the floor of the water chamber. Should too much air enter the cylinder, lifting it too high, the plates are pulled apart, the air escapes through the perforated plate, and the cylinder falls to the proper level. This obviates any liability to splashing of water, which, before this attachment was made, would occur if attention was not paid to a line painted on the cylinder to indicate cessation of pumping. By means of the automatic escape-valve we are enabled to introduce a continuously acting pump if desired.

As an additional precaution against splashing, the air chamber and overflow tank are each provided with a deflecting hood about an inch and a half wide, and inclined at an angle of forty-five degrees.

With these improvements over its original construction, being the gradual suggestions of six years' experience, the compressed-air apparatus is felt to be complete. There is no particular in which I find it deficient, or can now think of a change which would increase its mechanical convenience or therapeutic efficiency.*

I have for some time been endeavoring to combine with it an apparatus for expiration into rarefied air—a procedure which has a certain limited degree of applicability, being sometimes employed alone, sometimes in combination with the inhalation of compressed air. There was no difficulty in constructing an apparatus merely for expiration into rarefied air. All that was necessary was to reverse the connection with the bellows, so that the latter would take air from the gasometer and deliver it into the room or the street, and to suspend the air chamber from a small pulley, counterpoising it with weights varied according to the desired negative pressure. The mechanical arrangement of

* My friend, Dr. D. D. Stewart, suggests that care be taken that the rubber tubes employed are not of the variety weighted with lead.

pulleys and weights, the devices for adjusting the weights, the lowering of the outer water-tank (now a reservoir, and not for overflow), etc., are so obvious and so easily understood by looking at the instrument before us ("Rarefied air," Fig. 1) that description in detail is unnecessary. Mr. Metzger has made the various parts with his accustomed care, and has used a wire rope in preference to one of hemp. The difficulty lay in the combination of the two gasometers into one instrument by means of a bellows which should, at the same stroke, compress air for delivery into one cylinder and rarefy air in order to exhaust the other cylinder. As we could not get any bellows manufacturer to construct this, Mr. Metzger at last made an experimental one with his own hands (see Fig. 1), and it answers the purpose perfectly. It is in reality two bellows, mounted back to back, on the same frame. The downward stroke of the lever compresses the upper bellows and expands the lower one. The recoil of the spring in the upper bellows expands that one and compresses the other. There is no communication between the two bellows. By means of a tube (2, 3) passing out of a window-board (1), the external opening being protected by wire gauze, the supply of air for inhalation is drawn from out of doors.

When both instruments are used together, as I show now, being brought into communication through the lungs of a patient by means of a double stop-cock connected with the face-mask or mouth-piece, the route for the air is as follows:

(*a*) From the street, (*b*) through the upper bellows, (*c*) to the compression gasometer, (*d*) thence to the lungs; (*e*) from the lungs (*f*) through the rarefaction gasometer (*g*) to the lower bellows, (*h*) which expels it into the room or into the street.

Apparatus for warming, drying, or moistening the inhaled air may be interposed at any desired point between the window and the patient.

The compression and rarefaction are made in the respective bellows. The gasometers act, to a certain extent, as reservoirs, but chiefly as intermediate regulating chambers, rising and falling to maintain a constant pressure in exact accordance with the weight placed upon them, and independent of the volume of air inhaled or exhaled, their available capacity being a little more than eight hundred cubic inches.

For purposes of observation, sufficiently accurate for clinical comparisons, though not for physiological data, the air chambers carry a scale of cubic inches, enabling us to see the approximate volume of air inhaled or exhaled at each respiration.

I have yet to describe the stop-cock by which the ingress or egress of air to or from the face-mask or mouth-piece is governed. It is modeled on the cornet-piston, and consists of a central barrel, carrying a hollow cylinder, controlled by a spring, and a horizontal tube, communicating freely with the central barrel. The face-mask or mouth-piece (14, Fig. 1) is connected with the proximal extremity (13) of the horizontal tube; the delivery tube of the compression gasometer (10, 11) with the distal extremity (12). The inner central cylinder contains two, or rather three, perforations. Two of these are opposite to each other, and, when brought in line with the horizontal tube, form with it a continuous channel. In this position air is allowed to pass from the compression apparatus through the mouth piece or face-mask to the air-passages of the patient. The other perforation has no opposite fellow, and is on the side facing the mask or mouth-piece, so that when it is brought opposite the horizontal tube the air enters from the patient's lungs, and escapes through the inferior opening (15) in the central barrel. If it is desired to have exhalation made into rarefied air, this inferior extremity of the central barrel is connected (16, 17, 18) with the rarefaction gasometer. If the rarefaction apparatus only is to be used, the attachments to the compression gasometer are, of course, omitted.

If it is desired to have the patient exhale into compressed air, instead of connecting the stop-cock with the rarefaction gasometer, we can insert into this lower opening (15) an expiration resistance valve, as made for me by Messrs. Codman and Shurtleff, of Boston, and described in the "New York Medical Journal" for December 3, 1887.

If it is desired to have him inhale rarefied air, instead of connecting the stop-cock with the compressed-air apparatus, we insert into the horizontal tube (12) an inspiration resistance valve.

The "resistance valves," which I have called by that name because they offer a resistance to the passage of air, are simply little cylinders containing ebonite valves controlled by spiral springs. The tension of the spring is regulated by screwing the cap of the cylinder, and a scale engraved upon the side gives its value in fractions of an atmosphere. The expiration valve is arranged to move *toward* the perforated distal end of the cylinder, thus allowing the expiration current to escape whenever the pressure of the expired air reaches the indicated figure. The valve of the inspiration cylinder is arranged to move *from* the perforated top of the cylinder, thus allowing the inspiration current to pass toward the patient whenever the rarefaction within the lung reaches the indicated figure. The two valves, suitably mounted in one instrument, may be used independently of the gasometers (Fig. 2).

Thus, with these two gasometers, the double bellows, and a pair of resistance valves, we are able to obtain the mechanical satisfaction of all the conditions required for any of the following therapeutical expedients:

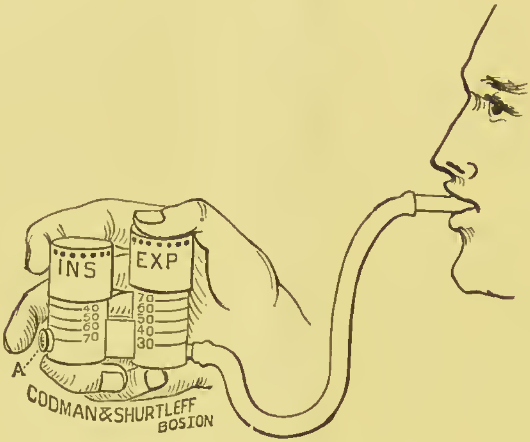

FIG. 2.

1. Inhalation of compressed air.
2. Inhalation of rarefied air.
3. Exhalation into compressed air.
4. Exhalation into rarefied air.
5. Inhalation of compressed air with exhalation into compressed air.
6. Inhalation of rarefied air with exhalation into rarefied air.
7. Inhalation of compressed air with exhalation into rarefied air.
8. Inhalation of rarefied air with exhalation into compressed air.

If a pump and motor are substituted for the foot-bellows, the only inconvenience connected with office use of the apparatus can be obviated. The additional cost is not excessive, and it leaves the apparatus still well within the price of any other capable of doing the same work.*

* Mr. Metzger sells either the compression or rarefaction apparatus singly, with all necessary attachments, for $30, and the double appa-

My endeavor has been throughout to use the simplest and least expensive methods and mechanical devices, and I have tried to induce the manufacturers to reduce their prices to the lowest point, in order to secure the widest possible and freest possible diffusion of the method, which I look upon as one of the most valuable within the reach of the therapeutist. The therapeutic expedients most generally employed are inhalation of compressed air and exhalation into rarefied air, and I shall speak of these only and briefly.

In using the apparatus the patient should preferably stand, but he may sit if necessary. If a face-mask is used, it should be accurately adjusted over the nose and mouth, and made to lie close to the cheeks to prevent escape of air. A glass mouth-piece may be used instead of a face-mask in many cases; and it is unnecessary to close the nostrils, as the nose and mouth can not be conveniently employed together for forced respiration, and there will be no interference. Each patient should have his own mask or mouth-piece.

At first the smallest pressures only should be employed ($\frac{1}{70}$ or $\frac{1}{60}$ atmosphere), and these may be gradually increased according to indications. It is never advisable to exceed $\frac{1}{30}$ atmosphere. From ten to fifty or even one hundred respirations, occupying from five to twenty minutes, are made continuously, beginning with the smallest number and gradually increasing. After inhaling for a while, say ten minutes, a rest of ten minutes or more is taken, after which the process is repeated. This may be gone through

ratus for $50. With pump and electric motor, the cost would be increased from $25 to $35 additional. Codman & Shurtleff sell the resistance valves for $5 a pair. Both manufacturers inform me that the time necessary to secure accurate adjustment of all parts of the apparatus in order to insure uniformity of pressures, and the present limited demand for the instruments, render it impossible for them to reduce these figures still further, as I have requested.

with once, twice, or three times daily, according to indications. Where the patient has an instrument at his home, it is employed more frequently than when it is necessary to visit the physician's office in order to obtain the facilities.

The physiological effects of these expedients are very apparent. The effect upon the circulation of increasing the pressure within the thorax, as compared with the pressure upon the periphery, by inhalation of compressed air, is, in brief, to drive the blood toward the point of least pressure —that is, out of the thorax. On the other hand, the effect of exhaling into rarefied air, thus increasing the pressure upon the periphery, as compared with that within the thorax, is to drive the blood into the heart and lungs.

The effect upon the respiratory act is equally obvious. If the pressure within the thorax be made greater than that without, expansion will be effected with less muscular effort. The air-cells are fully dilated, and occluded areas of lung tissue are forced open where the pathological process is not of such a nature as to prevent this result. There is also pressure upon the inflammatory congeries of new cells and upon congested blood-vessels, tending still further to increase the amount of available lung tissue, and to a certain extent to relieve congestion and promote resolution of inflammation. It acts as pressure by means of the bandage acts in external inflammations. The activity of the pulmonary circulation being increased, as well as the activity of the systemic circulation, a greater volume of blood passes through the pulmonary capillaries in a given time, and is exposed to a greater amount of oxygen under pressure—conditions which slightly favor the absorption of oxygen. As the increased volume of blood carries a greater number of corpuscles, theoretically it would seem that there should be a greater activity of oxygenation, and this has been confirmed by exact investigations conducted by Waldenburg, Speck, and others, and of which a full summary is given by Oertel in his admirable treatise. Subsequent expirations are freer and longer, and a greater amount of carbonic acid is given out, thus increasing pulmonary ventilation. Masses of desiccated secretion, desquamated epithelium, etc., are mechanically dislodged and their expulsion by cough facilitated, so that at first cough is increased. It is afterward lessened by correction of the conditions producing it. In the light of our present knowledge of auto-intoxications, the cleansing of the lungs from these decomposing masses of effete material must be considered of no little advantage.

Expiration into rarefied air facilitates emptying of the lungs, and, consequently, contraction of the chest is more complete. Subsequent inspirations are deeper.

By exhaling into rarefied air after inhaling compressed air we emphasize the difference between the two processes, and make an alternation of pressure-effects upon the vessels. All the effects before noted are thus heightened. An improved respiratory habit—that is to say, a fuller, freer, and more regular habitual respiration—is brought about, and the gain in vital capacity is very great. Not only is the exhalation of carbonic acid favored, but the subsequent absorption of oxygen is augmented on account of the greater extent to which emptying of the lungs has been secured. The alternating effects upon the alveoli increase the elasticity of the lung tissue. The alternate filling and emptying of the vessels stimulates circulation, increasing both rapidity and volume.

I am aware that doubts have been cast on the possibility of increasing the absorption of oxygen. Be this as it may, the effect clinically is to vastly stimulate and increase the nutrition of the patient. By careful observation I have been led to attribute this increase of nutrition to the ease with which the patient is able to dispose of the greater amount of nutriment which we administer. A patient over-fed but not taking inhalations of compressed air, will not increase so rapidly in weight as one who is overfed and at the same time taking these inhalations. A patient taking inhalations of compressed air and not overfed will not increase in weight. I have thought that the great gain was due to the stimulation afforded to the secondary assimilation and to the general metabolism. Tissue respiration and the activity of the chylopoietic processes are increased by the increased activity of circulation, the heightened blood pressure, the augmented pulmonary gaseous exchange, and also by the pressure transmitted from the diaphragm upon the abdominal organs. Patients with pulmonary troubles who are taking iron will take larger quantities and bear it better. This is also the case in anæmia and chlorosis. One of the earliest manifestations of improvement is promotion of sleep, due partly to relief of cough and improvement of respiration; partly, perhaps, to improvement of metabolic processes and consequent elaboration of physiological hypnotics. There is also an obvious gain afforded by the exercise to the chest muscles, to which a portion of the augmentation in vital capacity must be attributed. Some four or five years ago I published a number of personal observations on the increase in the chest capacity from inhalation of compressed air. The results were not so remarkable as some of those published by European observers, but they indicated a gain of from twenty to thirty cubic inches in respiratory capacity, and from half an inch to an inch and a half in chest expansion. This was in patients in whom chest expansion and respiratory activity had been impaired by condensation of the lung from phthisical or pneumonitic processes, or from the presence of pleuritic effusion. Pressure stimulates absorption of pleural effusions, and after the effusion has been absorbed the inhalation of compressed air tends to hasten the re-establishment of the normal action of the lung.

In two cases of asthma I have overcome the spasmodic dyspnœa of the acute attacks by the inhalation of compressed air at rather great pressure ($+\frac{1}{30}$ to $+\frac{1}{20}$ atm.). I suppose that the rationale of the effect is, in part, the paralyzing of the spasmodically contracted muscles of the bronchioles by the increased pressure of the air, and in part the relief of fluxionary congestion by direct pressure upon the engorged vessels, acting somewhat upon the principle of Monell's method of fixing the feet against the foot-board of the bed, taking a deep inspiration and holding it as long as possible.

The pneumatic expedient which has afforded the best permanent relief in asthma, especially when dependent upon emphysema, is, I think, expiration into rarefied air. This promotes collapse of the distended air vesicles and tends to relieve the lungs of the accumulation within them and, to a certain extent, to obviate paralytic distension in consequence of the presence of a greater amount of air than they should normally contain. It can not, of course, restore destroyed septa.

I have also thought, in common with those observers of largest experience in pneumotherapy, that the inhalation of compressed air had some good effect in the treatment of dilated heart from the pressure exerted upon the pulmonary vessels and cardiac chambers. Latterly I have employed in this condition expiration against pressure by means of the resistance valve, an expedient still more physiological. I have not used expiration into rarefied air in these cases, believing it to be counter-indicated, although it has been recommended by some.

There are many other obvious clinical applications of this method of treatment, but my object in bringing the subject before the college has been more particularly to show what can be done mechanically by a simple apparatus which may be placed in the patient's home, and not to refer especially to therapeutic uses. These would depend upon the views of the physician, and the experience which he obtains in the management of the method. The greater that experience, the more confidently will he extend it.

The effects are purely physical and mechanical, and easily deducible from a knowledge of the physical and mechanical effects upon normal circulation and respiration.

The one great advantage of the compressed-air machine is that it will enable us to treat at home patients with phthisis or threatened phthisis; and especially to prevent the development of tuberculosis in patients having—perhaps with an apical catarrh as well—insufficient expansion, insufficient aeration of blood, insufficient nutrition, sluggishness of circulation, and impairment of the muscular apparatus of the thorax. These patients are often sent chasing around the world in the vain search for a restorative climate, but very few receive benefit, except, of course, such good as may be incidental to an outdoor life. There are, however, a very great majority of persons whose circumstances preclude the possibility of leaving home. I have elsewhere indicated how we may by a few simple expedients imitate many of the features of special climates.*

I have not had a wonderful number of cases under my care, so that I can not give any extended statistics. But every year I see several cases of phthisis benefited and three or four cases improved in a remarkable manner. There is one case in particular which is in my mind, because I received a letter from the patient to-day:

* "Artificial Climatic Effects for 'Stay-at-Homes,'" "Philadelphia Med. Times," Feb. 6, 1886.

It is that of a Bostonian, thirty-two years of age, who spent last winter in Philadelphia and, although the weather was unfavorable and she had an intercurrent pleurisy, made a good recovery. She had a large cavity in the right lung and a smaller cavity in the left lung. All of her father's family except her father, and many of her mother's family, died of consumption. Her mother was said to have had consumption, but recovered under open-air life, forty years ago, and is hale and hearty. The father, who is some sixty-five years old, has fibroid phthisis, and is now breaking down. She was seen by Professor Da Costa at the beginning of the treatment and at the end, and he was able to verify both the pulmonary conditions and the great gain. When she began treatment her weight was 107 pounds; when she left Philadelphia in May it was 135 pounds, and in a letter received to-day she states that she now weighs 152 pounds. She had an evening temperature of 100·5° F., and all the troublesome symptoms of phthisis in the stage of softening. She went home with normal temperature and troubled only by more or less coughing, which has steadily decreased. The treatment was simply that of nutrition, overfeeding with nitrogenous and fatty aliments, whisky and hot water, aided by inhalation of compressed air, which enabled the increased quantities of food to be disposed of. The patient was kept out of doors as much as possible, and instructed to take deep and slow respirations continuously. Medication was principally symptomatic, for relief of cough, for disinfection of the alimentary tract, or for stimulation of digestion. She was given at different times creasote, iodoform, arsenic, amyl nitrite, and compound spirits of ether, with inhalations of terebene, chloroform, or ethyl iodide from the Yeo (perforated zinc) respirator, or from the Oliver nebulizer. I must not forget to add, in defense of a method of treatment now abused in neglect, as formerly in extravagant use, that the Bergeon injections of hydrogen sulphide and carbon dioxide served a useful temporary purpose in controlling a recurrent suppuration in the partially healed cavity of the right lung, following the pleurisy.

This woman evidently inherits a consumptive diathesis—but also a good recuperative force, which only required to be put under favorable conditions. She had a machine at her hotel, and she obeyed orders as to diet with religious exactitude.

Patients who recover like this, stay recovered. I have two patients treated in 1883 and reported in 1885, who are still well; and some of my brother's cases referred to at the opening of these remarks have been well for twelve and thirteen years. Even patients that do not recover can be greatly improved. Life is not only prolonged, but it is made much more comfortable. And to return to what I deem the most important considerations, the treatment is essentially a home treatment, and it is within reach of those of moderate means.